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Tillage and Cropping System Effects on Selected Conditions of a Soil Cropped to Grain Sorghum for Twelve Years

Getachew Alemu,[a] Paul W. Unger,[b] and Ordie R. Jones[b]

[a]*Sirinka Research Center, P.O. Box 74, Woldia, Ethiopia*
[b]*U.S. Department of Agriculture, Agricultural Research Service, P.O. Drawer 10, Bushland, TX 79012*

ABSTRACT

Soil and water conserving practices must be used to sustain dryland crop production in semiarid regions. In this 1994 study, we evaluated the effects of different cropping system and tillage method treatments on surface residue cover, organic matter content, aggregation, and water infiltration for a soil used for grain sorghum [*Sorghum bicolor* (L.) Moench] production in the United States Southern Great Plains from 1982 to 1994. Cropping systems were continuous sorghum (CS) and winter wheat (*Triticum aestivum* L.)—fallow—grain sorghum—fallow (designated WSF) and tillage methods were no-tillage (NT) and stubble mulch tillage (SMT). Treatments were CS-NT, CS-SMT, WSF-NT, and WSF-SMT. Surface residue cover before planting sorghum was >70% with CS-NT and WSF-NT, 29% with CS-SMT, and 12% with WSF-SMT. Surface cover after planting was ≈50% with both NT treatments, whereas amounts with other treatments were similar to those before planting. Soil organic matter contents (0- to 10-cm depth) were greater on CS than on WSF plots, but were not affected by tillage method in either cropping system. Water stable aggregation (0- to 2-cm depth) was greater with SMT than with NT in both cropping systems, but differences between cropping systems were not significant. Dry aggregates were smaller with

NT than with SMT. Water infiltration was or tended to be greater on CS than on WSF plots, apparently because the WSF plots contained more water when infiltration was measured. Infiltration was not affected by tillage method, apparently because the greater amount of surface residues on NT plots counteracted the less water stable aggregates and smaller dry aggregates that had potential for reducing infiltration on the NT plots. This study indicates that no cropping system-tillage method combination treatment had a consistently beneficial or detrimental effect on soil conditions. In conclusion, both cropping systems (CS and WSF) and both tillage methods (NT and SMT) are suitable for conserving soil and water resources and, therefore, for sustaining dryland crop production in the semiarid United States Southern Great Plains.

INTRODUCTION

Dryland (non-irrigated) farming has been an important part of the United States Great Plains agriculture since the region was placed under crop production in the late 1800s and early 1900s. Irrigated crop production rapidly increased in the Southern Great Plains (parts of New Mexico, Oklahoma, and Texas) after World War II and occupied over half of the cropland in parts of the region by the 1970s. Declining water supplies and major increases in energy costs since the mid-1970s have led to a renewed emphasis on dryland crop production in parts of the Southern Great Plains.

In much of the Southern Great Plains, the climate is semiarid and the potential for soil erosion, especially by wind, is great. To sustain crop production under such conditions, especially with dryland farming, land must be protected against erosion by using appropriate tillage methods and cropping systems. Furthermore, the methods and systems employed should result in adequate water storage in soil to achieve good crop growth and yields. Good crop growth also can help protect land against erosion, either while the crop is growing or through subsequent effective management of crop residues.

A major component of a successful dryland crop production system is having the soil profile filled with plant-available water to the anticipated depth of rooting at planting time. Within limits, the yield potential increases with increases in the amount of stored soil water. For example, each additional 1 mm of plant-available water stored in soil at planting above the threshold value of 50 mm increases sorghum grain yield an average of 17 $kg{\cdot}ha^{-1}$ at Bushland, Texas, in the Southern Great Plains (Jones and Hauser, 1975). Therefore, soil water storage during the non-crop or fallow period is extremely important for successful dryland crop production.

Numerous factors influence soil water storage. Those influenced by tillage methods and cropping systems include conditions at or near the soil surface that affect water infiltration and soil water evaporation. Included are surface residue amounts and cover, and soil crusting, aggregate stability, and organic matter content. Water infiltration also is indirectly related to soil bulk density. For optimum storage (conservation) and subsequent use by the next crop, water should readily enter soil and be stored within the plant root zone at a depth where its potential for loss by evaporation is low. A soil surface comprised of water-stable aggregates that resist dispersion due to raindrop impact or covered by crop residues generally provides for rapid water infiltration. Surface residues also reduce subsequent soil water evaporation. In general, water storage increases with increases in the amount of crop residues retained on the soil surface (Greb, 1979; Mielke et al., 1986; Unger, 1984). Surface soil water-stable aggregation and residue production and retention are influenced by tillage methods and cropping systems employed for crop production.

Surface residues are highly important for controlling wind and water erosion, with protection improving with increasing amounts retained on the soil surface. Also, dry soil aggregates >0.84 mm in diameter are important for controlling soil erosion by wind. On large, bare, smooth, unprotected fields, about 75% of the surface soil aggregates (or clods) should be >0.84 mm in diameter to keep average annual soil losses due to wind erosion below the tolerable level of about 11 $Mg \cdot ha^{-1}$ for many soils (Woodruff and Siddoway, 1965). Tillage methods and cropping systems influence surface soil dry aggregate size and residue production and retention, which are important for controlling wind erosion.

Besides their influence on soil and water conservation, crop residues play an important role in maintaining soil productivity by providing a source of nutrients and inputs to organic matter (Schomberg et al., 1994). The contribution of crop residues to soil productivity is frequently cited as a primary benefit associated with conservation tillage cropping systems (Jones et al., 1994).

The objective of this study was to compare effects of tillage methods and cropping systems used for dryland grain sorghum production in a semiarid region on some soil physical conditions and organic matter content, which are important for soil and water conservation.

MATERIALS AND METHODS

The research was conducted in 1994 at the USDA-ARS Conservation and Production Research Laboratory in Bushland, Texas (35°11'N, 102°5'W, 1180 m above mean sea level). The soil was a slowly permeable Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) that retains about 230 mm of plant-available water in the profile to a depth of 1.8 m. Average annual precipitation at Bushland is 475 mm (1939 to 1993), with about 75% occurring from May through September.

A study for winter wheat and grain sorghum production involving dryland cropping system and tillage method treatments was established in 1982 on leveled plots that were 9 m wide and 160 m long. Leveling was across the natural slope, which was 1.5% before leveling. All farming operations were done with commercially-available equipment. The 1982-1994 study had a randomized-block design with treatments replicated three times. Cropping systems evaluated in the 1994 study were those involving grain sorghum, namely, the sorghum phase of the wheat-fallow-sorghum-fallow (commonly designated wheat-sorghum-fallow, WSF) rotation and continuous sorghum (CS). The WSF system involves one winter wheat and one sorghum crop in a 3-year period. For the WSF system on dryland, wheat usually is planted in September or October and harvested in June or July. After wheat harvest, a fallow period of 10 to 11 months occurs before grain sorghum is planted, usually in June of the following year. Sorghum usually is harvested in October or November and is followed by a fallow period until wheat planting again the following year, thus completing the 3-year cycle. A crop is grown each year in the CS system, with planting and harvesting times comparable to those for the WSF system. Although grain sorghum was planted in 1994, results of that crop are not included in this report.

No-tillage (NT) and stubble mulch tillage (SMT) treatment plots had been established for both cropping systems. Cropping system-tillage method treatments evaluated in the 1994 study were CS-NT, CS-SMT, WSF-NT, and WSF-SMT. No-tillage plots had not been disturbed by tillage since 1982, except for some surface disturbance during crop planting. The SMT plots were tilled 7 to 10 cm deep five times during each fallow period of the WSF system and three times between crops of the CS system. A Richardson Sweep Plow[1] with one 1.5- and two 1.8-m-wide V-shaped blades was used for SMT.

In NT treatment plots, glyphosate [*N*-(phosphonomethyl)glycine] and atrazine [6-chloro-*N*-ethyl-*N'*(1-methylethyl)-1,3,5-triazine-2,4-diamine] were applied for weed control. Weed control and seedbed preparation in SMT plots were achieved with the sweep plow. The NT and SMT treatments resulted in retention of all or some residues on the surface for both cropping systems.

Surface residue amounts before and after planting sorghum in 1994 were determined by the line transect method (Laflen et al., 1981; Morrison and Lemunyon, 1994) at four sites per plot. This method involves use of a 15.2-m-long nylon cord that has knots at 15-cm intervals. The cord was stretched diagonally across the crop rows. Then walking along the cord, knots that had a piece of residue greater than about 3-mm in diameter (or width) under the leading edge when sighted from directly above were counted. The number of 'hits' divided by the total number of possible 'hits' (knots in the cord) times 100 gives the percent residue cover on the soil surface.

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[1]Mention of a trade name or product does not constitute a recommendation, endorsement, or exclusion for use by the U.S. Department of Agriculture, nor does it imply registration under FIFRA as amended.

Before planting sorghum in 1994, bulk soil samples from the 0- to 2-cm depth were obtained with a flat-bottom spade at three sites per plot and composited into one for determining water stable aggregation. After air drying, a portion of the soil was crushed and sieved to obtain 1- to 2-mm diameter aggregates. Duplicate subsamples of the aggregates were then wetted under vacuum and sieved in water to determine the percent remaining on a 60-mesh (0.25-mm) screen (Kemper and Rosenau, 1986).

Samples for dry aggregate size distribution were obtained with a flat-bottom spade from the 0- to 2-cm soil depth at three sites per plot. After air drying, a rotary sieve was used to separate the aggregates into six size fractions from which the size distribution was determined (Kemper and Rosenau, 1986). Mean weight diameters (MWDs) were calculated also.

Samples for bulk density determination were obtained with a tractor-mounted, hydraulically-powered coring machine to a 65-cm soil depth at two sites per plot. Cores were 5.4 cm in diameter and were separated into 0- to 10-, 10- to 20-, 20- to 35-, 35- to 50-, and 50- to 65-cm depth increments. The cores were weighed, oven dried, and weighed again before calculating the bulk density from the core weight and volume. A portion of the core soil from the 0- to 10-cm depth was finely ground (<0.50 mm) and used for determining the OM content on duplicate subsamples by the modified Walkley-Black method (Jackson, 1958).

Water infiltration was determined by using a rotating-disk rainfall simulator that applied Ogallala Aquifer water to a 1.5-m^2 area at a rate of 50 $mm \cdot hr^{-1}$ and at a kinetic energy similar to that of natural rainfall (Morin et al., 1967). Water was applied for at least 1.5 hours at two sites per plot. To eliminate the canopy effect, sorghum plants were cut at the soil surface and removed from the measurement area before applying the water.

Results from the duplicate laboratory analyses and the multiple determinations in the field were averaged before statistically analyzing the data using STATGRAPHICS® (version 4.0) software (STSC, Inc., 1991). When the F-test showed significance at the P=0.05 level, Duncan's multiple range test (LeClerg et al., 1962) was used to separate the means.

RESULTS AND DISCUSSION

Treatments did not affect soil bulk densities, but they increased with soil depth. Bulk densities averaged 1.47 $Mg \cdot m^{-3}$ at the 0- to 10-cm depth, 1.49 $Mg \cdot m^{-3}$ at the 10- to 20-cm depth, 1.65 $Mg \cdot m^{-3}$ at the 20- to 35- and 35- to 50-cm depths, and 1.73 $Mg \cdot m^{-3}$ at the 50- to 65-cm depth.

Tillage methods significantly affected the amount of residues remaining on the soil surface before and after planting sorghum (Table 1). Residue cover was 76% in CS-NT and 77% in WSF-NT plots before planting. These large amounts on NT plots resulted from no residue incorporation by tillage and from slower

TABLE 1. Effects of tillage method and cropping system treatments on surface residue coverage, organic matter content, water-stable aggregation, and infiltration in 1994 for a soil used for grain sorghum production at Bushland, Texas, from 1982 to 1994.

	Surface residue coverage				
Treatment[a]	Before planting	After planting	Organic matter	Water-stable aggregation	Infiltration
	%				mm
CS-NT	76a[b]	50a	1.56a	61bc	38.7a
CS-SMT	29b	33b	1.54ab	74a	36.2ab
WSF-NT	77a	52a	1.44bc	53c	32.0ab
WSF-SMT	12c	25c	1.42c	69ab	30.8b

[a]Treatments: CS-NT, continuous sorghum, no-tillage; CS-SMT, continuous sorghum, stubble mulch tillage; WSF-NT, wheat-sorghum-fallow rotation, no-tillage; WSF-SMT, wheat-sorghum-fallow rotation, stubble mulch tillage.

[b]Column values followed by the same letter or letters are not significantly different at the 0.05 level of probability according to the Duncan's Multiple Range Test.

decomposition than on SMT plots. Weed debris on the surface contributed to the greater residue cover with NT. After planting, residue cover was 50 to 52% on NT plots, whereas residue cover changed little on the remaining plots.

Soil OM content ranged from 1.42% in WSF-SMT plots to 1.56% in CS-NT plots (Table 1). There was no difference in OM content due to tillage method within either cropping system, but OM content was lower, regardless of tillage method, in WSF than in CS plots, which agrees with results of other studies on this soil that indicated soil OM generally is greater with annual cropping than with cropping systems involving fallow periods (Johnson and Davis, 1972; Unger, 1972).

Aggregates (1- to 2-mm size range) that were water stable ranged from 53% for the WSF-NT treatment to 74% for the CS-SMT treatment (Table 1). Aggregates from SMT plots were more stable than those from NT plots in both cropping systems. Consequently, if the same results would be obtained for all sizes of aggregates, water infiltration under field conditions could be greater with SMT than with NT for both cropping systems (WSF and CS) because dispersion of surface aggregates results in development of a surface seal, which then decreases water infiltration. Infiltration is affected, however, by soil conditions other than water stability of aggregates. Also, more crop residues on the surface could offset the possible adverse effect of less-stable surface aggregates with NT, which appeared to be the case in this study. Infiltration was similar with NT and SMT,

TABLE 2. Effects of tillage method and cropping system treatments on dry aggregate size distribution and mean weight diameter (MWD) in 1994 for a soil used for grain sorghum production at Bushland, Texas, from 1982 to 1994.

Treatment[a]	Aggregate size (mm)							
	<0.42	0.42-0.84	0.84-2.0	2.0-6.4	6.4-18.3	>18.3	Total >0.84	MWD
	%							mm
CS-NT	35.4a[b]	22.7ab	12.8ab	13.0b	12.9bc	3.2b	41.9b	4.0b
CS-SMT	23.9b	19.8b	15.4a	16.8a	17.6a	6.5b	56.3a	6.3a
WSF-NT	38.2a	27.2a	9.7b	9.2c	11.9c	3.8b	34.6c	4.0b
WSF-SMT	28.0b	20.6b	15.7a	15.3ab	16.3ab	4.1b	51.4a	5.0ab

[a]Treatments: CS-NT, continuous sorghum, no-tillage; CS-SMT, continuous sorghum, stubble mulch tillage; WSF-NT, wheat-sorghum-fallow rotation, no-tillage; WSF-SMT, wheat-sorghum-fallow rotation, stubble mulch tillage.

[b]Column values followed by the same letter or letters are not significantly different at the 0.05 level of probability according to the Duncan's Multiple Range Test.

as discussed later. The difference in water-stable aggregation between cropping systems was not significant.

In this study, all cropping system-tillage method combination treatments resulted in less than the required amount (75%) of large aggregates (total percentage >0.84 mm diameter) to effectively control wind erosion (Table 2). Treatments affected the percentages in the different size ranges, with the total percentage of >0.84-mm aggregates being greater in SMT plots of both cropping systems (WSF and CS) than in NT plots. Soil with NT of both cropping systems (WSF and CS), therefore, potentially would be more susceptible to wind erosion than with other treatments. However, surface residues in NT fields were adequate to protect soils against wind erosion, thus negating the potential adverse effect of the lower percentage of large aggregates.

The MWD of dry aggregates ranged from 4.0 mm for CS-NT and WSF-NT plots to 6.3 mm for CS-SMT plots (Table 2). Also, the MWD for both cropping systems was lower with NT than with SMT. In general, the MWD and dry aggregate size distribution results suggest that soil in NT plots of both cropping systems would be more susceptible to wind erosion than soil in SMT plots. However, greater amounts of surface residues with NT would offset this potential adverse effect of aggregate size on wind erosion.

Cumulative infiltration was greater in CS-NT than in WSF-SMT plots, but the difference between the NT and SMT methods within either cropping system was not significant (Table 1). In WSF plots, infiltration rate decreased rapidly and runoff increased rapidly (data not shown) after about 10 min of water application, apparently because the WSF plots contained more water than CS plots when infiltration was measured. More surface residues on NT plots counteracted the less water stable aggregates and the greater percentage of small dry aggregates that had potential for reducing water infiltration on the NT plots. As a result, water infiltration differences due to tillage methods were not significant.

CONCLUSIONS

No cropping system-tillage method combination treatment had a consistently beneficial or detrimental effect on soil conditions. The NT treatments as compared with SMT treatments resulted in greater surface residue cover, but less water-stable aggregates and fewer large dry aggregates (based on total percentage >0.84 mm and the MWD). These positive and negative factors counteracted each other. As a result, differences in water infiltration were small. Therefore, from a soil condition viewpoint, it is concluded that both cropping systems (CS and WSF) and both tillage methods (NT and SMT) are suitable for conserving soil and water resources and sustaining crop production under dryland conditions in the semiarid United States Southern Great Plains region.

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